METALCUTTING
CORPORATION

Properties and Applications of Tungsten Wire

How Unique Traits of Tungsten Wire Make Application Performance Achievable

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Introduction: Unique Properties of Tungsten

In a day and age when the most familiar use of tungsten — the wire filament of an incandescent light bulb — continues to fade, why do we still talk about this gray-white metallic element? It's because it has a unique range of properties that make tungsten wire irreplaceable (or nearly so) in a number of important products and industrial applications.

USEFUL CHARACTERISTICS OF TUNGSTEN

Tungsten is one of the so-called refractory metals, along with molybdenum, niobium, rhenium, and tantalum. These materials are known primarily for their high melting points.

In fact, tungsten has the **highest melting point of all known metals**, at 6192°F (3422°C), along with a number of other very useful characteristics, including:

- Resistance to oxidation and creep
- Extreme hardness
- High electrical resistance
- The lowest vapor pressure of all metals
- High tensile strength

Tungsten has long served industry based on its unique properties — sometimes because of just one unique property, sometimes based on a combination.

For example, with its high melting point and ability to retain its characteristics at elevated temperatures — maintaining its low vapor pressure and tensile strength at upwards of 3000°F (1650°C) — tungsten is often the material of choice for very high-temperature applications.

Learn more about the melting point of tungsten in our blog **5 Interesting Facts About Tungsten.**

HEAT RESISTANCE

While incandescent filaments have mostly been replaced, "big science" has not found a replacement for tungsten's unique melting temperature in vacuum electron devices (VEDs) such as traveling wave tubes (TWTs), magnetrons, and klystrons.

These devices provide the high power density at high frequencies that silicon-based and even gallium-based solid state electronics simply cannot achieve. For example, TWT amplifiers are indispensable for modern radio frequency (RF) applications when sending high power signals significant distances — and they cannot function without tungsten

From broadcast satellites to air traffic control to space-based weapon systems, tungsten is vital to function. And any hope to use plasma heating to develop nuclear fusion, advances in particle acceleration, and future terahertz technologies all rest on the availability of tungsten.

LOW VAPOR PRESSURE

Tungsten is also indispensable for metal injection molding (MIM) furnaces that use refractory heating elements instead of graphite ones, which introduce potentially damaging reactive carbon.

In these MIM hydrogen atmosphere furnaces, the non-oxidizing environment takes advantage of tungsten's low vapor pressure. This allows the furnaces to reach very high temperatures without releasing oxygen, carbon, moisture, or other contaminants.

SHAPE RETENTION

Because it maintains its shape at high temperatures, tungsten is often used as a material for **welding electrodes**.

In addition, ultra high-temperature diamond coating would not be possible without tungsten. These vapor deposition coating furnaces are filled with diamonds that are exposed to extremely high heat transmitted uniformly via an array of suspended tungsten wires.

HIGH DENSITY

The specific high density of tungsten has many uses, including life-saving radiation shielding, collimators and sputtering target material, and even military inertial weapons systems. Safer than lead and lower priced than gold, tungsten offers the benefit of its compact weight for applications such as aerospace ballast and vibration dampening balance components.

While tungsten's unique melting point gives it a limited range of alloy options, those that work, work very well.

For instance, many of the density-driven products above are often machined using heavy alloy, a sintered product that combines tungsten with nickel and either copper or iron. The result is a machinable form of tungsten that can be pressed and sintered into shapes beyond the scale of pure tungsten wrought products.

In these and other ways, tungsten as an element and in its many forms continues to be indispensable in a modern industrial and high-tech world.

WORKING WITH TUNGSTEN

PROCESSING

Grayish-white in color, tungsten metal is not found "standalone" in nature. Instead, like many ores, it must undergo an extraction process in order to be in a usable form for manufacturing.

But unlike some ores, tungsten cannot be extracted and refined using traditional smelting processes. Because of its high melting point — and the impracticality of having a container that can withstand that high a temperature without melting — tungsten simply cannot be manufactured in a liquid state.

Rather, it is typically manufactured using **powder metallurgy** and a series of chemical reactions.

Most often, tungsten is extracted from **wolframite** or **scheelite** ore that is crushed, cleaned, and processed to produce **ammonium paratungstate (APT)**. The APT can be treated with alkalis to form multiple stages of oxides, known as **tungsten trioxide (WO3)**, which can then be heated in a hydrogen atmosphere and reduced to produce tungsten metal powder.

Using tungsten metal powders, products are made through pressing and sintering in near net shape — or, for tungsten wire and rod wrought products, the material undergoes an additional process of swaging and repeated drawing and annealing after it has been pressed and sintered.

It is this complex, multistep process that produces the characteristic elongated grain microstructure that carries over into finished products such as very thin wires and large rods. (**More on this later.**)

Tungsten powders and oxides can also be blended in with other metals and materials to create products with unique properties. For instance, tungsten carbide is the most prevalent cemented carbide for the manufacture of high-speed cutting tools.

Tungsten powder added to iron, platinum, and even polymers yields unique products in fields as diverse as electronics, metrology, and medicine. Even in lighting, tungsten oxides will remain useful for fluorescence long after filaments have receded.

CHALLENGES

As useful as the properties of tungsten are, there can be some challenges in working with it. For instance, pure tungsten is difficult (though not impossible) to machine.

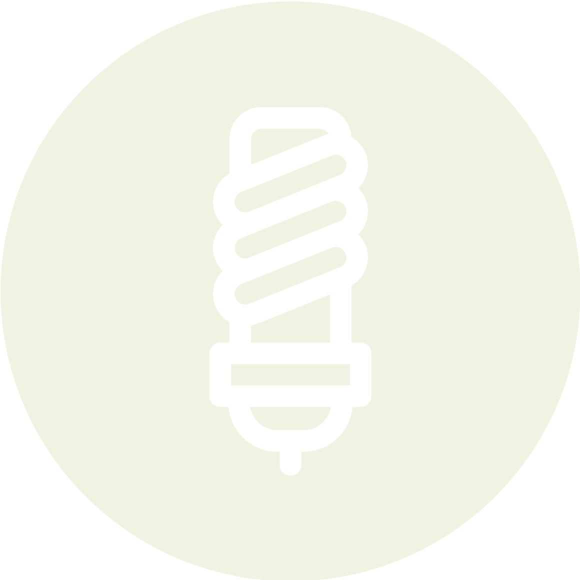
The diamond tools that are used for machining tungsten carbide are ineffective for pure tungsten, which becomes compacted into the spaces between the diamonds — a condition known as loading, which renders the (expensive) cutting tool unable to cut. Pure tungsten also cannot be drawn over a mandrel or extruded into a tube.

The metallurgical reason why it is notoriously difficult to fabricate with pure tungsten is that it is one of several metals that is ductile only above a specific temperature, known as the **ductile-to-brittle transition temperature (DBTT).**

Tungsten's transition temperature is usually higher than room temperature, giving the material poor ductility and making it very brittle at low temperatures. The exception is tungsten wire, where the addition of heat actually provides forming benefits.

Tungsten can also become brittle and difficult to work with when it is impure or contaminated with other materials. It oxidizes in air at elevated temperatures, which is why welding with tungsten requires a protective gas atmosphere or reducing atmosphere to prevent the material from breaking down.

Nonetheless, tungsten is valued for its unique properties and is used in a wide range of applications. Even as compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) promise to forever change the lighting industry, tungsten continues to be used in the manufacture of fluorescent bulbs and the filaments for traditional incandescent bulbs.



PROPERTIES OF TUNGSTEN AS WIRE

To get from powder to wire, tungsten is subjected to **pressing, sintering, swaging, drawing**, and **annealing** at elevated temperatures in hydrogen atmospheres. So, you might think that the metal undergoes significant changes in properties during that process.

However, the wire ultimately does retain many of the valuable characteristics of tungsten, such as its:

- High melting point
- Low coefficient of thermal expansion
- Low vapor pressure

In addition, tungsten wire demonstrates useful electrical and thermal conductivity, which explains why it is used extensively for lighting as well as in electronic devices and thermocouples.

Most tungsten wire today is **doped**, which means it has undergone an additional process that provides the wire with **non-sag properties**. Doped tungsten wire can remain ductile at room temperature as well as at very high operating temperatures.

While doping was initially developed to improve tungsten wire's use in incandescent light bulb filaments, it continues today in tungsten wire manufacturing and is an advantage for other high-temperature applications, such as industrial ovens and **vacuum metalizing**. (**The importance of dopants in tungsten wire** is discussed in greater detail below.)

In addition, some companies — including Metal Cutting Corporation — offer **undoped tungsten wire** for applications where the highest purity is required. At this time, the purest tungsten wire available is 99.99% pure, made from 99.999% pure powder, and offered by Metal Cutting.

Unlike ferrous metal wires, which are available annealed to a wide range of tensile strengths, the tensile strength of pure tungsten wire varies only with diameter. The strength cannot be adjusted significantly by customized annealing schedules.

However, between different manufacturers, tungsten wire at the same diameter will have slightly different tensile strength values. This is due to differences in their respective tungsten wire manufacturing processes, such as the pressed bar size, swaging equipment, and drawing, reduction, and annealing schedules.

In the next section, we will delve deeper into the history of tungsten and how tungsten wire is made.

The Foundation of Tungsten Wire

A BRIEF HISTORY OF TUNGSTEN

WHEN WAS TUNGSTEN DISCOVERED?

While early reports of tungsten date back to the mid-1500s, it was not identified as an element until 1781.

That's when Swedish chemist Carl Wilhelm Scheele discovered that a new acid, which he called **tungstic acid**, could be made from a mineral now known as scheelite. Scheele and a Swedish professor, Torbern Bergman, later developed the idea of using charcoal reduction of tungstic acid to obtain a metal (tungsten).

HOW WAS TUNGSTEN METAL FIRST PRODUCED?

Then in 1783, Spanish chemists (and brothers) Juan José Elhuyar and Fausto de Elhuyar found tungstic acid in samples of a mineral called **wolframite** (from which we get the symbol for tungsten, W). The brothers were able to isolate the substance as a metal, using the process suggested by Scheele and Bergman.

In the coming decades, scientists experimented with various applications for this "new" metal and its compounds. Still, the high cost of tungsten made it impractical for industrial use.

By 1847, British chemist Robert Oxland had decoded and patented processes for manufacturing tungsten in various metallic forms, including tungsten trioxide, sodium tungstate, and tungstic acid. These processes made the production of tungsten metal more cost-effective, opening the door to its use in industrial applications.

For example, due to its hardness and strength at high temperatures, tungsten was widely used in the manufacture of high-speed steel. The later development of durable cemented tungsten carbides drove growth in the tooling, drilling, and construction industries.

Today, tungsten is the most widely used refractory metal and is still extracted using the same basic methodology envisioned by Scheele, Bergman, and the Elhuyar brothers.

Wondering how tungsten is used in everyday life today? Read our blog **Tungsten Uses Then and Now**.

TUNGSTEN AND THE EVOLUTION OF THE LIGHT BULB

Thomas Edison is widely credited with inventing the incandescent light bulb, filing a patent for his carbon filament lamp in 1879. However, he is just one of many scientists who pursued the creation and improvement of the incandescent light filament throughout much of the nineteenth century and into the twentieth.

This was especially true given the drawbacks of carbon filament bulbs, which were inefficient and produced a weak light. Despite carbon's high melting point, the high operating temperature of the lamp caused carbon to evaporate from the filament and coat the inside of the bulb — dimming the bulb even further and quickly burning it out entirely.

So, scientists around the world were working to find a metal filament that could operate at a higher temperature and produce a brighter and more efficient light bulb. The results were mixed:

- Austrian Carl Auer van Welsbach's 1898 osmium filament was more efficient than carbon, but the lamps were difficult and expensive to make.
- In the early 1900s, Germans Werner von Bolton and Otto Feuerlien invented a tantalum filament lamp, which was less efficient but produced a brighter light than osmium.
- In the United States, General Electric chemist Willis Whitney was using an electrical resistance furnace to bake carbon filaments at very high temperatures to produce metal-like properties.

While Whitney's "GE Metallized" (GEM) lamps were an improvement, they were no match for the lamps being developed in the Austro-Hungarian empire. There, Sándor Just and Franjo Hanamann were working on a new tungsten lamp that would prove to last longer and produce brighter light than the carbon filament lamp.

And in 1904, the duo patented the granddaddy of tungsten wire applications — **the first tungsten filament light bulb**. It soon edged out the less efficient carbon filament and revolutionized artificial lighting.

To this day, incandescent bulb filaments continue to be made from tungsten, making it an essential element in the **evolution of the lighting industry**.

HOW TUNGSTEN WIRE IS FABRICATED

Tungsten wire can be drawn to any wire diameter, even as small as 0.00025” (0.006 mm), with as-drawn, electropolished, and plated surface finishes. Aside from a few alloys, tungsten wire is generally available **pure** (or **unalloyed**) or **doped** (or **non-sag**) to meet different product and application needs.

BASIC STEPS OF TUNGSTEN WIRE PRODUCTION

As we mentioned earlier, powder metallurgy is most often the starting point for tungsten products, including tungsten wire. Powder metallurgy allows for better fabrication and is less expensive than a method such as vacuum arc-casting or electron-beam melting.

Using tungsten powder, the wire fabrication process generally goes like this:

- First comes **pressing**, which is exactly what it sounds like — and it is the stage where tungsten power begins to take the bar form from which wire will eventually be produced.

  Here, tungsten powder that has been milled, sifted, blended, and weighed is put into a tool-steel breakaway mold and loaded into a hydraulic press, where it is compacted into a bar held together by wax and pressure. The homogeneity of the bar and its size are the foundation of the quality of the wire that will result.
- In **pre-sintering**, the bar — which is still quite fragile — is placed into a high-temperature hydrogen atmosphere furnace, where the material begins to consolidate until it reaches 60% to 70% of theoretical density. This ensures that the bar is strong enough to be clamped and sintered.
- In **sintering**, the bar is treated with electric current in a hydrogen atmosphere. This generates heat and causes the bar’s density to increase to 93%; at the same time, the bar shrinks and tungsten crystals begin to form. At this point, the as-sintered bar is now very strong but brittle at room temperature.
- In **swaging**, the bar is repeatedly heated to make it malleable, lubricated, and passed through a swager — basically, rotating ball peen hammers — to incrementally reduce the diameter of the bar with each pass. This step elongates the crystals and creates a fibrous structure that will provide ductility and strength in the final product.
- Now the tungsten is ready for **drawing** — the point where the swaged wire is lubricated and drawn through a series of tungsten carbide or diamond dies to further reduce the diameter. The drawing process also further elongates the wire’s fibers and increases its tensile strength.

DETAILS ON DRAWING TUNGSTEN WIRE

The as-sintered tungsten bar is generally swaged down to a wire with a diameter of about 0.10” (2.54 mm) before drawing. While the exact gauge of the swaged wire when drawing begins can vary, the bar must have been worked by swaging at least 97% so that the material is ductile enough for drawing.

The parameters that must be precisely controlled during the drawing phase are the **wire temperature, drawing speed, lubricant, drawing dies,** and **reduction ratio**.

In addition, since the metal becomes work hardened during drawing, the wire is generally **annealed** between passes to return it to a ductile state for further drawing. This involves passing electricity through sections of the wire in a hydrogen atmosphere and then cooling it.

As a rule, drawing is not used to produce tungsten wire diameters less than 25 to 75 microns, depending on various differences between manufacturers. Finer wires can be produced by methods such as etching in alkaline potassium ferricyanide, electrolytic etching, or cathodic thinning in an argon discharge.

The exact number of drawing passes, and the reduction ratios in between them, are closely guarded industrial secrets for each manufacturer. However, it is generally accepted that at least ten drawing passes are needed to develop a satisfactory surface and uniform diameter in the final drawn wire product.

CLEANING TUNGSTEN WIRE

After the tungsten wire is drawn, it can be shipped to customers in the “as-drawn” condition. In applications where the highly abrasive tungsten wire will pass over mandrels or on to other tooling as part of the customer’s manufacturing, the drawing lubricant can serve as a beneficial layer to extend tool life.

The customer’s product made from the wire can be cleaned afterwards as needed. However, the results will not be as good as passing the wire spool to spool through an electrochemical cleaning and polishing bath.

For applications where the wire must be free of any surface impurities, the tungsten wire manufacturer will offer electrochemical cleaning and polishing to remove the coating layer of graphite, excess oxides, and contaminants.

This process uses various combinations of AC and DC current in a chemical bath equipped with an array of anodes and cathodes strategically positioned to fully clean wire as it passes through the bath.

MAKING PURE VS. DOPED TUNGSTEN WIRE

Doped tungsten wire has typically been produced in diameters from 0.040” (1 mm) to the smallest diameters possible, usually 0.00025” (0.006 mm), for use in wire filament applications, as well as in vacuum metalizing, diamond deposition, and other traditional high-temperature applications.

The big difference between making unalloyed tungsten wire and making the non-sag variety is the **addition of dopants to the tungsten powder**. Generally, the process involves reducing APT to tungsten oxide and then reducing it further with an aqueous solution of aluminum compounds (aluminum chloride or aluminum nitrate) and potassium silicate.

Doped tungsten oxide is reduced to metal powder more quickly than non-doped. After blending, drying, hydrogen reduction, leaching, washing, and more drying, this process results in doped tungsten metal powder.

From there, the doped tungsten undergoes much the same process of pressing, sintering, swaging, and drawing to ultimately produce non-sag tungsten wire. However, this is a greatly simplified description, and there are some other differences along the way.

For example, in the sintering stage, the compacted bar of doped tungsten is usually made smaller than a comparable bar of pure tungsten, and in a shorter time. That is because doped tungsten achieves density more easily than pure tungsten.

Swaging and drawing are similar, except that doped tungsten requires additional in-process annealing since it has a higher rate of work hardening than pure tungsten. The annealing temperature is also higher, to ensure that the proper structure and non-sag properties are achieved.

Finally, the quality of finished non-sag wire is inspected for five critical parameters: **wire diameter, diameter variation, amount of splitting (crack detection), tensile strength,** and **recrystallization behavior**.

In the next section, we'll take a closer look at why dopants and non-sag tungsten wire are so important, along with some other interesting forms and functions of tungsten.

Unique Insights into Tungsten

THE SIGNIFICANCE OF DOPED (NON-SAG) TUNGSTEN WIRE

As you can guess, the development of doped tungsten wire is inextricably linked to the history of the incandescent light bulb — and specifically, to the evolution of the coiled tungsten filament.

EVOLUTION OF TUNGSTEN WIRE FILAMENTS

Just and Hanamann's patented incandescent bulbs of the early 1900s used straight tungsten filaments. They were made by mixing tungsten compounds with a carbonless binder, extruding the mixture into a tube, and heating it in hydrogen to produce the metal filament.

While these early tungsten filaments had a downside — brittleness — they still made the carbon filament obsolete due to their improved light output and greater efficiency (lumens per watt).

Within a few years, experiments in GE's lab led to the development of drawn tungsten wire filaments that were more ductile, resulting in improved material strength. However, the filaments still became brittle and quickly failed under the tungsten light bulb's high-temperature conditions.

The theory was that brittleness and offsetting (sliding) of the wire's grain boundary resulted from a weakening of the wire's crystalline structure, making the filament unstable. This was where **the importance of recrystallization temperatures** began to enter the conversation.

The next big improvement came with the discovery that the life of a light bulb depended on the evaporation of tungsten from the filament. Scientists found that filling the bulb with an inert gas slowed the evaporation, produced less blackening of the bulb, and improved product life.

They also found that a filament with a larger diameter evaporated more slowly, due to the presence of more inert gas surrounding the filament's surface.

This led to the practice of twisting the tungsten filament into a coil to, in effect, make the overall filament diameter larger — which in turn led to the coiled construction where an inch of filament actually consisted of a meter of coiled wire.

While coiled tungsten filaments were brighter and lasted longer, there was still a problem: Under the influence of gravity, the coiled filaments tended to lose their shape at high temperatures, causing the filaments to sag, arc, and fail.

DEVELOPMENT OF NON-SAG TUNGSTEN WIRE FILAMENTS

With the challenge of this deformation in coiled tungsten filaments, attention turned to creating a doping method that would produce tungsten wire filaments with non-sag qualities.

Experiments with doping around 1913 had shown that it caused tungsten filaments to recrystallize to form very small crystals. Then in 1917, Aladar Pácz developed a process using tungstic acid doped with potassium, sodium, and silicon, and then reduced to metal powder, pressed, and sintered.

During sintering, the dopant volatilized out at the temperature where rapid grain growth began to occur. And amazingly, the sintered bar showed continued grain growth in subsequent rounds of heating. The result was non-sag tungsten filaments with a coarse grain microstructure and large crystals that resisted creep.

Meanwhile near London, the Battersea Company was inadvertently demonstrating that the way tungsten oxide is produced has an impact on the quality of metal powder and its end products. This is because manufacturers found that tungsten oxide treated in clay crucibles, especially those made by Battersea, produced tungsten filaments that were more stable at incandescent temperatures.

A later analysis showed the presence of aluminum compounds, potassium, and silicon during powder processing, with only trace amounts of potassium remaining after sintering. Eventually tungsten plants began adding those “contaminants” deliberately.

This intentional use of **alumina-potassium-silicate (AKS)** doping was an important step in powder metallurgy and a crucial development in non-sag tungsten wire. The exact chemistry of doping continued to evolve and improve throughout the first half of the twentieth century.

Today, doped tungsten wire continues to be used in coiled filaments for incandescent lamps. It has also expanded into other uses because its non-sage properties are important for critical applications such as metal furnaces and diamond deposition.

ENSURING QUALITY IN TUNGSTEN WIRE DOPING

Today, the fabrication of non-sag tungsten wire filaments begins with choosing a high-purity tungstic acid or APT. The purity is important because impurities can have a negative impact on the workability of tungsten and their high vapor pressure can impair the function of the wire at high temperatures.

Next, tungsten oxide must be prepared from tungstic acid or APT so that it will pick up the dopant (AKS). There are different “lower oxides” — for example, blue, violet, brown, and gray — and not all of them are suitable for doping.

This process of converting tungsten oxide to the proper lower oxide requires precisely controlling factors such as the temperature, rate, and atmosphere used in material reduction. The process is done with hydrogen and either rotary furnaces or tube furnaces; while the former optimizes the driest hydrogen, rotary furnaces are often preferred for their higher throughput.

This is followed by the proper blending of the oxide and dopant, and a highly controlled dispersion of the dopant during further reduction of the oxide by hydrogen. This homogenous blend helps to ensure the proper grain size and distribution in later steps of wire fabrication.

For quality control, the tungsten power is measured for characteristics that have an impact on the ability of the tungsten powder to be pressed and compacted, including:

- Mean particle size
- Apparent density
- Tap density
- Green density
- Particle size distribution
- Identification of impurities such as oxygen, iron, and potassium

These factors also affect how the tungsten particles interlock and grow, ultimately forming bubble rows of the correct size, density, and length.

Excess dopant is removed from the metal powder by acid washing prior to pressing and pre-sintering. Further evaporation of the dopant in sintering removes most of the aluminum and silicon, while potassium remains behind due to its high vapor pressure, causing the formation of voids and bubble rows in the tungsten material’s structure.

From there the doped tungsten continues through the process of swaging, annealing, and drawing **as described above**.

Taking care to ensure that there are no interruptions at any step in the process — from powder preparation through drawing — is crucial to avoiding issues of splitting, brittleness, cavitation, and sagging in the finished wire product.

BENEFITS OF AN ELONGATED GRAIN STRUCTURE

The trace amount of potassium that remains behind after powder reduction and further volatizing during sintering is another vital factor in the effectiveness and quality of doped tungsten wire.

The potassium concentration has been shown to raise the recrystallization temperature of tungsten wire. This increases the density of the bubble rows and allows the large, elongated recrystallized grains to be formed more easily.

As the wire is worked, grain growth perpendicular to the wire axis is reined in by the bubble rows in the areas of recrystallization. At the same time, the bubble rows continue to form and extend along the axis.

The proper arrangement of bubble rows prevents grain boundary sliding, giving the doped wire its non-sag quality (deformation resistance) and enhancing its high-temperature strength. The elongated, stacked structure of doped tungsten wire also provides properties such as:

- Ductility at room temperature
- Increased tensile strength at room temperature
- Good creep resistance
- Dimensional stability
- Somewhat easier machining than pure (undoped) wire

A NICHE FOR TUNGSTEN RIBBON

Another unique tungsten product occupying a somewhat small niche is tungsten ribbon, which generally comes in two forms:

- Extremely high-volume ribbon manufactured and produced for mechanical applications
- Precision rolled for applications requiring ribbon for glass to metal seals in vacuum assemblies

High-volume tungsten ribbon has cross-sectional ratios from 2:1 to 10:1 for applications such as catheter shafts and borescopes. The product is optimal where a blend of round wire and flat ribbon is necessary, along with tungsten's unique properties at higher volumes and lower prices.

For example, where today's braided catheter shafts are often made from a combination of steel wire and steel ribbon, and sometimes tungsten wire, they could instead be made from high-volume tungsten ribbon.

Rolled tungsten ribbon is used in applications including traveling wave tubes and radar, x-ray, microwave, and vacuum tubes. This method produces the highest quality split-free ribbon with corner geometries that maintain uniform edges, and offers very wide ratios.

THE NEW WAVE: SURGICAL ROBOTICS

Tungsten wire has been used in the **medical device industry** for many years, mostly in cautery. But since about 1992, ultrafine tungsten wire has played a new and growing role — namely, in miniature robotic cables that are the basis of robotic-assisted surgery.

Other robots "operate" in a variety of environments, from automobile factory floors to the depths of the sea, to the far reaches of outer space. But in surgery, the robot does not operate (literally) remotely or alone — it is used to convey the surgeon's movement from a workstation to the distal end of the device, to the surgical site in the patient.

When surgical robotics were first being developed, the big selling point was the removal of tremor, whether from fatigue during the course of a long procedure or from small, natural movements that are possible with even the steadiest hand. Today, precise location is equally important.

For robotic-assisted surgical systems, tungsten wire is essential for robotic cables where positional accuracy is paramount. In fact, robotic cable is the biggest application for tungsten wire right now — and it is one for which there is no real substitute.

Because tungsten wire has no springback, there are many medical applications for which it is not suitable. However, since tungsten wire has virtually zero elongation, it is ideal for the cables used in robotic-assisted surgery — eliminating the risk of the cable stretching, and helping a surgeon perform precise procedures with perfect positional accuracy.

Braided tungsten wire robotic cables are highly engineered, complex “cables of cables.” A single 0.02” (0.50 mm) diameter tungsten cable may be made of hundreds of tiny individual wires that are 0.001” (0.025 mm) in diameter (about a third the size of one human hair) or even as tiny as 0.0005” (0.0127 mm).

While tungsten wire is somewhat more expensive than stainless steel wire, a common wire cable metal, because of tungsten’s unique elongation properties, there is no substitution for it in robotic surgical cables.

There are other applications and products for which tungsten wire is the best option — some of which we will discuss in the next section.

Additional Applications for Tungsten Wire

Besides being essential to the manufacture of coiled lamp filaments and surgical robotic cables, tungsten wire is used in a wide range of other products where its properties are highly valued.

GENERAL INDUSTRY

With its unique combination of properties that are hard to find in any other material, tungsten wire is used in a variety of general industry applications — especially where strength and resistance to deformation at elevated temperatures is an advantage.

CORONA DISCHARGE

Corona discharge is often done and best accomplished with tungsten wire. For air filtration, printers and copiers, and other applications, only tungsten wire produces the ionization and surface modification required.

The tungsten wires used can be electropolished, have specialized oxide layers, or be gold-plated to produce the controlled electrical discharges used in laser printing, air filtration, and other corona discharge processes.

Learn more in our blog **Top Applications for Gold-Plated Tungsten Wire**.

FURNACES

In addition to tungsten's use in heating elements for high-temperature MIM furnaces, tungsten wire is widely used to provide support or pulling action in industrial ovens. This is due to tungsten wire's non-sag properties as well as its heat resistance.

So, for example, tungsten wire is often **woven into mats** used to position and hold objects in place in the engineered hot zone of industrial ovens, furnaces, and even kilns.

It is also vital to the manufacture of electronic devices such as integrated circuits, where it is braided into cable and strand for **semiconductor silicon pulling** — the process of making the boule (ingot) from which silicon chips are sliced.

Doped tungsten wire is used to make **helical springs** for devices that are baked at high temperatures during manufacture or exposed to high temperatures in their end use. Instrument suspensions, valves, and lamps are among the devices with springs that benefit from tungsten wire's high elastic modulus, high yield strength, and high temperature resistance.

PROBES

Additionally, the stiffness of tungsten wire even at very small diameters is a crucial factor in its use in various types of probes, including **cantilever semiconductor test probes** used for silicon wafer testing in semiconductor manufacturing. Stiffness is also an advantage in tungsten wire for **neural probes** used in medical diagnostics and treatment.

Learn more in our blog **A Closer Look at Utilizing Tungsten Wire for Probes**.

ELECTRODES

An alloy such as copper tungsten or silver tungsten is often chosen for the electrode used in **electrical discharge machining (EDM)**. However, tungsten wire is the only viable material for very specialized EDM erosion cutting wires for 50 micron or less kerfs on hard conductive metals with complex final shape geometries

It's an EDM application requiring wire with the appropriate fracture resistance, heat and electrical conductivity, low vaporization temperature, and hardness.

Additionally, having the highest tensile strength compared with other materials commonly used for EDM wires, tungsten wire can provide sharp cutting of very thin and flat-walled features. It is also used for EDM applications that must be free from copper or zinc residue on cut surfaces.

Tungsten and certain alloys — lanthanum, cerium, zirconium, and yttrium — are also used to make **electrodes for welding**. In **TIG (tungsten inert gas) welding**, these electrodes produce a more stable arc and retain their shape for accurate and consistent welds.

While thoriated tungsten wire was used for welding electrodes for many years, it is now out of favor due to the radioactivity of thorium and concerns for the health of welders and the environment. This has led to the development of alternative, non-radioactive materials such as the alloys mentioned above.

DEPOSITION APPLICATIONS

Earlier, we mentioned that tungsten wire is used in vapor deposition coating furnaces. One of the biggest applications for tungsten wire is in **vacuum metalizing**, a process for coating a substrate (such as plastic) with a metallic layer.

Here, the wire is used as the **vacuum metalizing coils** that disperse a vaporized metal to cover the surface of a wide range of products. Read **Utilizing Tungsten Wire in Applications for General Industry** to learn more about vacuum metalizing and other important uses of tungsten wire, including:

- Automobile turn signals
- Thermocouples
- Borescopes
- Electron emitting devices

LIGHTING APPLICATIONS

Since the first tungsten filament lamps were sold in Austria-Hungary back in 1904, lighting has played a vital role in modern life. From the house to the car to the street, from work to play to the stage, think of all the things that would be very different if not for the evolution of the light bulb.

Improvements in tungsten wire filaments and production processes continued over the decades after the light bulb became a hot — and practical — item. However, most of the improvements cut costs but did little for bulb efficiency. By about 1950, incandescent technology seemed to have gone as far as it could, and innovation came to a standstill.

IMPROVEMENTS TO INCANDESCENT LIGHTING

In the new century, the Energy Independence and Security Act (EISA) signed into law in 2007 phased in new standards designed to improve light bulb energy efficiency over time, including:

- Between 2012 and 2014, requiring all light bulbs to use 25-30% less energy than traditional incandescent bulbs
- In 2020, requiring everyday light bulbs (or general service lamps, GSLs) to use 65% less energy than traditional incandescent bulbs while delivering the same amount of light

Although the U.S. Department of Energy (DOE) later excluded some types of bulbs from the standards and rolled back the requirements and 2020 deadline, manufacturers have still risen to the challenge. Today, light bulbs of all types are more energy efficient, and most — especially CFLs and LEDs — have exceeded the minimum energy requirements.

Even incandescent light bulbs (which include halogen bulbs) are, on average, twice as efficient as they were in 2007. The incandescent bulbs available for purchase today have similar light output (lumens) as before, but with wattages reduced by about 30% percent.

CONTINUED HOUSEHOLD AND COMMERCIAL USE — BUT FOR HOW LONG?

As the movement toward energy efficiency continues, although in fits and starts, incandescent tungsten filament bulbs still seem destined to be displaced in the market unless further innovation occurs. For example, halogen bulbs, which are a large share of the remaining incandescent market, still use four times the power of LEDs.

Although incandescent tungsten filament light bulbs continue to be used in many U.S. households and businesses, the legislated phaseout has already begun in other places around the world, including the countries of the European Union.

Are there applications where other lighting alternatives have already taken hold? Let’s take a look.

- **Automobile Lighting** — You might have to search high and low to find a few incandescent bulbs in a typical grocery or hardware store, or even in a big box home improvement center. But one place where you will still find a lot of incandescent bulbs is the auto parts store. Read more in our blog **Tungsten Wire Refuses to Die in Automotive Lighting**.

- **Stage Lighting** — Stage lighting is used in television studios and on sound stages, as well as in venues where theatrical productions, concerts, and other live events take place. And while stage lighting still uses incandescent technology, it is usually in the form of proprietary **high-performance tungsten-halogen** (or quartz-halogen) lamps with carefully calibrated color temperature values to control overall scene rendition.

  These lamps use a halogen gas in place of an inert gas and a compact filament that concentrates the light, providing more controlled reflection and greater energy efficiency. Fluorescent lights may also be used in work areas backstage or behind the scenes, but the light you see "in performance" is incandescent.

- **Outdoor Lighting** — The use of **energy-efficient LED lighting** (often "fueled" with solar panels) is expanding on roads and highways across the country. In parking lots, old-style metal halide or mercury vapor lights are being replaced with LED products that provide a greater lighting radius and lighting strength.

  Although incandescent or halogen lamps are sometimes used for signage and billboards, solar or LED lighting is growing in popularity for these applications.

  In addition, digital LED-based billboards are another trend, although they have "luminance limits" based on billboard-to-viewer distances and the amount of light that can be safely emitted without distracting or impairing the vision of passing motorists.

- **Stadium and Arena Lighting** — Almost all of the overhead lighting in outdoor sports stadiums and indoor arenas uses **high intensity discharge (HID)** lamps. They provide the higher wattage these venues need, compared with other outdoor lighting applications such as billboards, roads, and parking lots.

  According to a DOE study, 17% of U.S. lighting energy consumption is used outdoors, and 83% of outdoor lighting consumption comes from HID. Because of their high output, HID lamps are also used in some warehouse and industrial applications.

  Although HID lamps are very efficient, they do take a long time to warm up and achieve full brightness. A case in point is Super Bowl XLVII in New Orleans back in 2013, when a power disruption and the subsequent re-warmup of the Superdome's HID lights caused a 34-minute delay in the game.

MEDICAL DEVICE COMPONENTS

While ultrafine tungsten cable used in **robotic-assisted surgical systems** has become a top application in recent years, tungsten wire has a long history of successful use in medical devices that take advantage of its unique properties including:

- Density equal to that of gold
- Comparatively high tensile strength and mineral hardness
- Low vapor pressure at high temperatures
- Highest melting point of any metal

For example, tungsten wire’s combination of hardness and tensile strength allows it to be used to make components that are stiff yet steerable, such as coil tips, catheter shafts, guide wires, electrodes, and probes.

The material’s density and radiopacity also allow tungsten wire to be used for applications such as fluoroscopy and radiology. With its melting point and stability at elevated temperatures, tungsten wire is used in electrocautery and electrosurgery.

You can learn more about these and other uses in our blog **Utilizing Tungsten in Medical Device Applications**. Additionally, gold plating of tungsten wire allows it to serve as a substitute for gold or other more expensive precious metals in **applications requiring a biomaterial**.

Conclusion

THE FUTURE OF TUNGSTEN WIRE PRODUCTION

There are those who say that change is inevitable and that everything will eventually be replaced by technical innovation. And it is true that the incandescent light bulb, tungsten wire's foundational application — and its formerly highest volume usage by far — is being replaced by more efficient technologies.

However, it is also true that, thanks to its elemental properties, there are applications for which there is no substitute for tungsten wire. Whichever of the element's unique set of properties is necessary — its high melting point, low thermal expansion, low vapor pressure, density, and/or electrical and thermal conductivity — there is often no other way to achieve performance than to have tungsten wire available for those applications.

FURTHER READING

To learn more about the basics of tungsten wire and its history, properties, and applications, download our free guide ***Tungsten Wire 101: Overview of a Uniquely Useful Material***.

In addition, if you're interested in a deep dive into the subject matter, we recommend the following resources:

C. Agte and J. Vacek, *Tungsten and Molybdenum.* Washington: NASA Translation, 1963.

Erik Lassner and Wolf-Dieter Schubert, *Tungsten: Properties, Chemistry, Technology of the Element, Alloys, and Chemical Compounds*. New York: Kluwer Academic/Plenum Press, 1999.

Erwin Pink and Lászlό Bartha, editors, *The Metallurgy of Doped/Non-Sag Tungsten*. New York: Elsevier Science Publishing Co., 1989.

Colin J. Smithells, *Tungsten*. London: Chapman & Hall, 1952.

Stephen W.H. Yih and Chun T. Wang, Tungsten: *Sources, Metallurgy, Properties, and Applications*. New York: Plenum Press, 1979.

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